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Performance Assessment of Incinerators and High Temperature Industrial Processes Disposing Hazardous Waste in the United States

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16. ABSTRACT

Since 1982, the U.S. Environmental Protection Agency (EPA) has been conducting performance assessments of hazardous waste thermal destruction facilities in the United States. The principal objective of these tests has been to characterize emissions and determine if these facilities are capable of meeting the waste destruction and control requirements of the current EPA regulations and standards. To date the test program has involved performance assessments at nine incinerators and over twenty high temperature industrial processes employing hazardous waste as a fuel supplement in their operations.

The testing has typically involved stack emissions assessment for SO_x, NO_x, particulate, HCl, CO, CO_2, O_2, metals, total hydrocarbon, and quantification of specific organic compound emissions. Engineering and other process operating varibles (e.g., excess air, steam load, waste to fuel ratio) have also been recorded during the test program in order to examine the potential operating bounds for these facilities.

The purpose of this paper is to summarize the extensive results of this testing program which has, in general, indicated that high organic compound destruction and removal efficiencies (99.99 percent) are achievable in these facilities. Effective (99 percent) control of HCl emissions was attained in facilities employing chlorinated organic wastes. The current EPA particulate standard of 180 mg/dry m^3 was the most difficult standard to attain for incinerators.

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PERFORMANCE ASSESSMENT OF INCINERATORS AND HIGH TEMPERATURE INDUSTRIAL PROCESSES DISPOSING HAZARDOUS WASTE IN THE UNITED STATES

by

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The author is responsible for directing U.S. Environmental Protection Agency (EPA) research pertaining to control of hazardous waste via thermal destruction and by conventional treatment technology. Research data from this program form the basis for regulations and standards developed for these processes under the Resource Conservation and Recovery Act (RCRA). The author has directed research programs in solid and hazardous waste management and advanced wastewater treatment in 15 years with EPA. He has received a B.S. degree in Civil Engineering and a M.S. degree in Sanitary Engineering from Cornell University and a MBA from Xavier University.

ABSTRACT: Since 1982, the U.S. Environmental Protection Agency (EPA) has been conducting performance assessments of hazardous waste thermal destruction facilities in the United States. The principal objective of these tests has been to characterize emissions and determine if these facilities are capable of meeting the waste destruction and control requirements of the current EPA regulations and standards. To date the test program has involved performance assessments at nine incinerators and over twenty high temperature industrial processes employing hazardous waste as a fuel supplement in their operations.

The testing has typically involved stack emissions assessment for SO_x, NO_x, particulate, HCl, CO, CO_2, O_2, metals, total hydrocarbon, and quantification of specific organic compound emissions. Engineering and other process operating variables (e.g., excess air, steam load, waste to fuel ratio) have also been recorded during the test program in order to examine the potential operating bounds for these facilities.

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KEY WORDS: hazardous waste, incinerators, industrial boilers, cement kilns, emissions sampling, trace organic compounds, thermal destruction

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has estimated that the United States generated 264 million metric tonnes (MMT) of hazardous waste in 1981 (1). A significant portion of this waste was predominantly non-hazardous material (water) contaminated with hazardous materials. While only a relatively small amount of hazardous waste was managed by thermal destruction (Table 1), EPA estimates that as much as 25 MMT could have been thermally destroyed (2). It is also significant to note that more than twice as much hazardous waste was disposed in industrial processes as fuel compared to that disposed in specially designed incineration systems.

TABLE 1--HAZARDOUS WASTE THERMAL DESTRUCTION FACILITIES (1981)

FACILITIES	WASTE MANAGED (Million Metric Tonnes/Year)
Incinerators (240 Facilities)	1.70
Industrial Boilers (~1300 Facilities)	3.50
Other Industrial Processes (Cement Kilns, Steel Furnaces, etc., (~20 Facilities)	.35
TOTAL	5.55

Until recently, there were only limited data available on waste destruction performance and pollutant emissions from thermal destruction devices. Studies by EPA and others in the early to late 1970's employed a variety of evolving trace organic pollutant sampling and analysis techniques and were often targeted only towards measuring macro-destruction and combustion efficiencies (3-5), rather than the performance standards now required under the Resource Conservation and Recovery Act of 1976 (RCRA). Since 1981, however, EPA has conducted a

significant program of performance testing at thermal destruction facilities. The program was designed to determine the environmental impact of these operations and to provide information on the ability of these facilities to destroy hazardous waste to the degree required by the 1982 incinerator performance standards. These standards require that facilities must demonstrate that they can attain: (1) 99.99 percent destruction and removal efficiency (DRE)* for each principal organic hazardous constituent (POHC) in the waste feed, (2) at least 99 percent removal of hydrogen chloride from the exhaust gas if hydrogen chloride stack emissions are greater than 1.8 kg/hr, and (3) particulate matter emissions no greater than 180 mg/standard m^3 corrected to 7 percent oxygen in the stack gas.**

This paper describes the procedures and results of performance testing which EPA has conducted over the past four years at incinerators, industrial boilers and industrial process kilns disposing of hazardous waste. These results are being used extensively in the analysis of the environmental and economic impact of implementing existing and proposed standards for control of the operation of thermal destruction facilities.

*$DRE = (W_{in} - W_{out})/W_{in}) \times 100$

Where: W_{in} = Mass feed rate of the principal organic hazardous constituent (POHC) in the waste stream fed to the incinerator.

W_{out} = Mass emission rate of the POHC in the stack prior to release to the atmosphere.

**Correction Factor = 14/(21-Y)

Where: Y = measured oxygen concentration in the stack gas on a dry basis.

The measured particulate matter concentration is multiplied by the correction factor to obtain the corrected particulate matter emissions.

EXPERIMENTAL APPROACH

Sampling and Analysis

The primary objective of the field testing programs was to characterize the emissions of incinerators, industrial boilers, and industrial processes burning hazardous waste under current industry operating practices in order to determine the ability of these facilities to meet existing and proposed control standards. Accomplishment of this objective required that each input and output stream be characterized to the greatest extent possible. Sampling locations, sampling and analysis methods, quality assurance/quality control (QA/QC) planning followed established EPA guidelines (7, 8), but were necessarily somewhat unique for each facility tested because of differences in system designs, operating practices, and waste characteristics. Typical input streams sampled included: waste feed, process feed (e.g., limestone feed to kilns), auxiliary or base fuel (in the case of boilers and kilns), and air pollution control system make-up and recycle flows. Output streams generally included: stack gases, air pollution control device effluent (solid or liquid), bottom residues (ash) or product (cement, lime, aggregate). Where appropriate, gas samples were collected before and after air pollution control devices to characterize their contribution to performance.

Composited grab samples were employed for fuels, waste feed, ashes, residues, and product streams. Extractive sampling techniques were employed to collect integrated samples of combustion and stack gases. Semivolatile organic compounds (boiling points greater than 130°C) and particulate matter were collected using a modified EPA Method 5 (MM5) sampling train, with minor differences from site to site. Organic pollutants were extracted from all portions of the sampling train, including the XAD-2 organic sorbent, filter media, and

impinger solution. Volatile organic compounds, those having boiling points <130°C, were generally sampled using the EPA volatile organic sampling train (VOST). However, because of the evolution of this new sampling train during the four year period of the test program, certain sites were tested with single trap systems or gas bags (EPA Method 23). Volatile compounds were thermally desorbed from the TENAX resin employed in the VOST and subsequently analyzed by GC/MS, or GC/EC.

Stack and combustion gases were also typically monitored continously for oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), sulfur oxides (SO_2), nitrogen oxides (NO_x) and, in many cases, total hydrocarbons (THC). Grab samples of wastes and fuels were also analyzed for heating value, proximate and utlimate analysis, and viscosity.

Each stream sampled was analyzed for hazardous organic constituents, chlorides, particulate or ash and, in some cases, metals of interest. Organic analysis of waste, fuel, and stack emissions samples was accomplished by GC/MS, GC/ECD, or GC/FID depending upon the selected organic groups sought in the analysis. Metals were most typically analyzed using ion capture detection methods.

Engineering and operating data were also collected for each facility. These data included waste and fuel feed rates, scrubber wastes feed, recycle and wastage rates, temperatures, and gas flow rates at critical portions of the facility and production related data for industrial processes (e.g., load and steam rate for boilers, clinker production rate for kilns).

Complete descriptions of the specific sampling, analysis, and QA/QC approaches employed in the field testing are provided in EPA final reports on the test program (9-12).

Site Selection and Testing Rationale

Test sites were selected to evaluate waste destruction over as broad a range of facility design, operational principles, and waste characteristics as possible. This was necessary so that EPA could generalize testing results and conclusions to the whole spectrum of hazardous waste management activities which might come under the thermal destruction regulation.

In the case of incineration, eight facilities were selected, including both commercial and on-site units. The testing encompassed rotary kiln, liquid injection, and fixed hearth technologies. Table 2 provides an overview of other important aspects of these sites.

The facility capacities ranged from 1 to 87 GJ/hr heat input. Values for three key parameters: combustion temperature, residence time, and percent excess air or percent oxygen also varied widely. Operating temperatures ranged from 650°C to 1450°C and calculated residence times varied from 0.07 to 6.5 seconds. Excess air values fell within a range of 60 to 130 percent. Corresponding oxygen values in the stack gas ranged from 8 to 12 percent.

Waste streams with a wide range of characteristics were encountered at the eight sites (Figure 1). Operating conditions during the tests were those selected by the plants as their normal conditions. In general, any obvious operating problems were corrected before the tests were initiated.

The industrial boiler facilities candidate test sites were screened based on representativeness of the boiler design and wastes being fired, and the availability and accessibility for cofiring tests. Within this context, preference was given to sites and waste fuels which were viewed as being less likely to attain a high level of waste destruction.

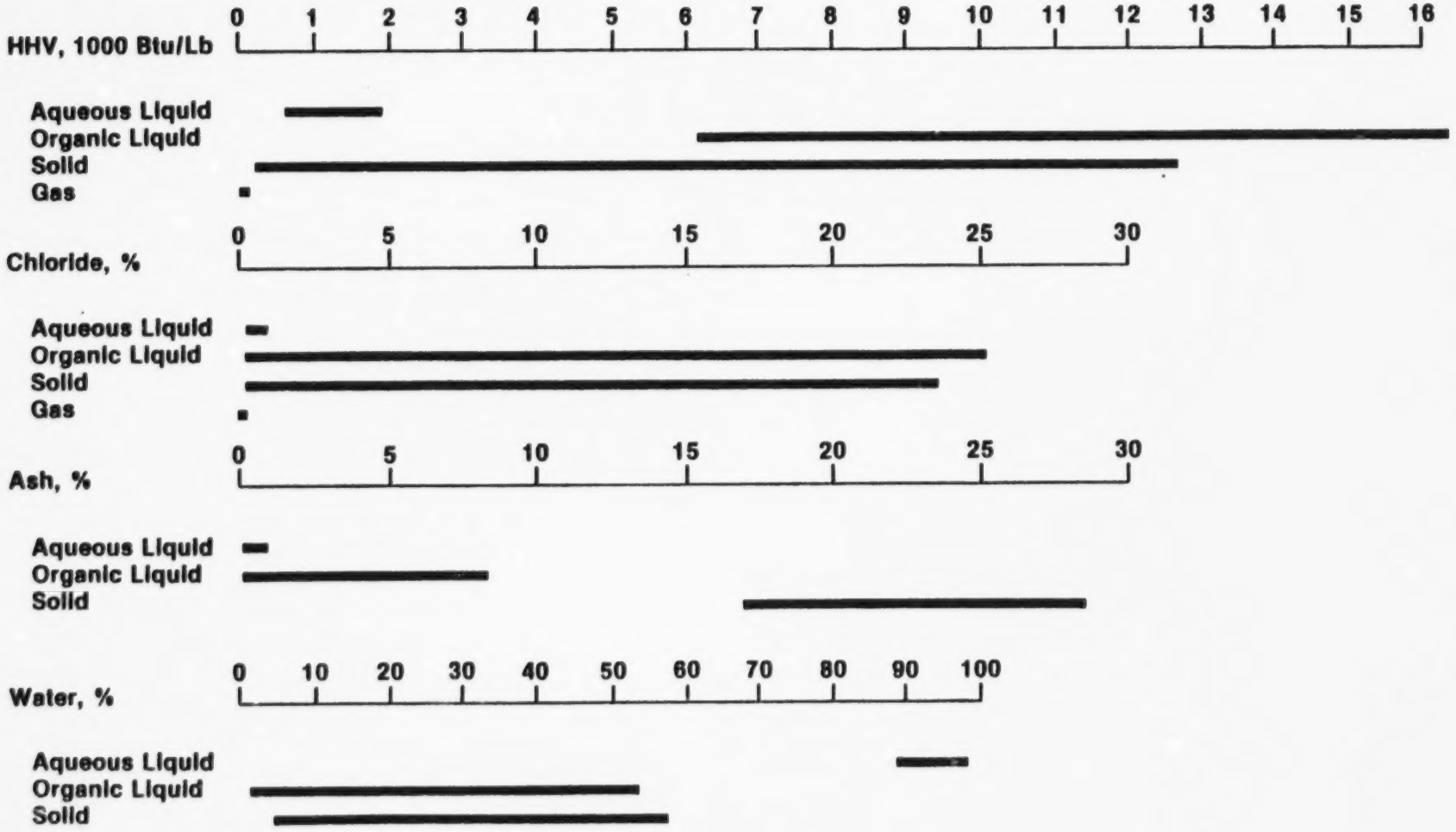
TABLE 2--DESCRIPTION OF INCINERATION FACILITIES TESTED

FACILITY TYPE	CONTROL DEVICE	WASTE	CAPACITY (GJ/HR)	TEMPERATURE (°C)	RESIDENCE TIME (Sec)
(1) Commercial Rotary Kiln/ Liquid Incineratr	Packed Tower Adsorber Ionizing Wet Scrubber	Drummed, aqueous, liquid organic waste with carbon tetrachloride, TCE[a], perchloroethylene, toluene, phenol	87	1139	6.5
(2) Commercial Fixed Hearth, Two Stage Incinerator	Electrified Gravel Bed Filter And Packed Tower Absorber	Liquid organic and aqueous waste with chloroform, carbon tetrachloride, TCE, toluene, perchloroethylene	25	Stage 1 1063 Stage 2 1011	6.2
(3) On-site Two-Stage Liquid Incinerator	Packed Tower Absorber	Liquid organic waste with carbon tetrachloride, dechlorobenzene, TCE, chlorobenzene, chloromethane aniline, phosgene	6	1116	5.2
(4) Commercial Fixed Hearth, Two-Stage Incinerator	None	Liquid organic waste with TCE, carbon tetrachloride, toluene, chlorobenzene	2	Stage 1 705 Stage 2 868	.07
(5) On-Site Liquid Injection Incinerator	None	Liquid organic waste with aniline, diphenylamine, mono and dinitrobenzene	4.8	681	.20
(6) Commercial Two-Stage Fixed Hearth Incinerator	None	Aqueous and organic liquid waste with carbon tetrachloride, TCE, benzene, phenol, perchloroethylene, toluene, methylethyl ketone	10	Stage 1 1097 Stage 2 1100	2.3
(7) On-site Rotary Kiln With/Liquid Injection	Venturi Scrubber With Cyclone Separators And Packed Tower Absorbers	Liquid organic, point waste and filter cakes with methylene chloride, chloroform, benzl chloride, hexachloroethane, toluene, TCE, carbon tetrachloride	35	Stage 1 769 Stage 2 980 Liquid 1450	Kiln/AB 7.3 Liquid .26
(8) Commercial Two-Stage Fixed Hearth Incinerator	Venturi Scrubber	Aqueous and organic liquids and solid waste with methylene chloride, chloroform, carbon tetrachloride, hexachlorocylopendstadiene, toluene, benzene, TCE	75	Stage 1 1092 Stage 2 1045	3.6

(a) TCE = trichloroethylene

FIGURE 1

WASTE CHARACTERISTICS



From a boiler design viewpoint, the test matrix addressed the major design categories of firetubes and watertubes and typical fossil fuels burned in these units. An earlier study on the estimates of time-temperature profiles in boilers had shown that although most boilers provide sufficiently high furnace temperature and residence time for efficient destruction of organic compounds, smaller units such as firetubes and small watertubes provide the least safety factor of time at high temperature (13).

Table 3 lists the eleven test sites selected for the field test program in the framework of the developed test matrix. The majority of the selected boilers were watertube designs in the 2.9 to 29 MW (10 to 100 GJ/hr) size category, employing either natural gas or heavy oil as the primary fuel. The waste fuels available at the selected sites were cofired as found. However, to facilitate intrasource comparison, the majority of test boilers were cofired with a "spike" mixture of organic compounds. Spiked compounds typically were carbon tetrachloride, chlorobenzene, and trichloroethylene, which were considered difficult to destroy. This practice was also employed in the incinerator and kiln tests where carbon tetrachloride, trichlorethylene, and various freons were also employed.

The tests typically included a baseline test (primary fossil fuel only) followed by a minimum of three cofired tests for replication of results. Steady-state boiler operation was sought during all testing to minimize the variation in test parameters with potential impact on DRE's and other organic emissions.

Eight industrial kiln facilities were tested. Site selection here was limited to facilities actually employing hazardous waste fuels in their normal operations. As can be seen in Table 4 these included both wet- and dry-process

TABLE 3--DESCRIPTION OF INDUSTRIAL BOILER FACILITIES TESTED

FACILITY TYPE	CAPACITY (GJ/HR)	PRIMARY FUEL	CONTROL DEVICE	WASTE
(1) Watertube Stoker	10	Wood Waste	Multiclone	Creosote Sludge With Phenol Pentachlorpheno And Napthalene
(2) Packaged Firetube	8.5	Natural Gas	None	Alkyd Wastewater With Toluene
(3) Field Erected Watertube	230	Gas or Oil	None	Phenol Waste
(4) Converted Stoker	90	No. 6 Oil	None	Methanol, Toluene And Chlorinated Organics Including Perchloroethylene
(5) Packaged Watertube	110	No. 6 Oil	None	Methyl Methacrylate By-products With Carbon Tetrachloride, Chlorobenzene And TCE(a)
(6) Converted Watertube	60	No. 6 Oil	None	Paint Solvents With Carbon Tetrachloride, TCE, Toluene And Chlorobenzene
(7) Modified Firetube	40	None	2 Scrubbers In Series	Highly Chlorinated Organics Including Carbon Tetrachloride
(8) Tangentially Fired Watertube	250	Pulverized Coal	ESP	Methyl Acetate, Carbon Tetrachloride, Trichloroethane Chlorobenzene
(9) Packaged Watertube	62	Natural Gas	None	Aniline Waste With Nitrobenzene, Carbon Tetrachloride, TCE, Benzene, Toluene
(10) Packaged Firetube	10	None	None	Toluene, Chlorinated Organics, Including Carbon Tetrachloride, TCE
(11) Packaged Watertube	60	No. 6 Oil	None	Blended Waste With Light Oil And Carbon Tetrachloride, Benzene, TCE, Toluene

(a) TCE = trichloroethylene

TABLE 4--DESCRIPTION OF INDUSTRIAL KILN FACILITIES TESTED

FACILITY	CAPACITY (GJ/HR)	PRIMARY FUEL	CONTROL DEVICE	WASTE
(1) Wet Process Cement Kiln (Non-atomized Waste)	140	No. 6 Oil	Fabric Filter	Waste Liquids Including, Methylene Chloride, Chloroform, Carbon Tetrachloride
(2) Wet Process Cement Kiln (Atomized Waste)	170	Coal	ESP	Waste Liquids, Including Methylene Chloride, MEK(a), Trichloroethane, Toluene, Freon 113
(3) Dry Process Cement Kiln (Non-atomized Waste)	228	Coal/Coke	ESP	Waste Liquids, Including Methylene Chloride, Freon 113, MEK, Toluene, Trichloroethane
(4) Dry Process Cement Kiln (Atomized Waste)	300	Coal/Coke	Fabric Filter	Waste Liquids, Including Trichloroethane, Trimethylbenzene, Xylene, Methylene Chloride
(5) Lime Kiln (Atomized Waste)	50	Coke/Natural Gas	Fabric Filter	Waste Liquids, Including Methylene Chloride, MEK, Trichloroethylene
(6) Shale Aggregate Kiln (Atomized Waste)	35	Coal	Scrubber	Waste Liquids, Including Perchloroethylene, Methyethyl
(7) Clay Aggregate Kiln	20	Coal	Scrubbers	Waste Liquids, Including Methylethyl Ketone, Perchloroethylene And Toluene
(8) Clay Products Kiln (Atomized Waste)	37.5	Waste Oil	Fabric Filter	Waste Liquids, Waste Oil, Freon 113, Perchloroethylene Carbon Tetrachloride, Benzene Toluene, Trichloroethylene

MEK = methylethyl ketone

cement kilns, a lime kiln, and three aggregate kiln facilities. The test matrix was also designed to cover a range of primary fuel type and air pollution control system design. Baseline tests (primary fuel only) and three replicate waste tests runs were employed as in the boiler evaluation program. Additionally, waste injection techniques were varied between the sites.

DISCUSSION OF RESULTS

Tables 5, 6, and 7 summarize the waste destruction performance and emissions data collected during the test program. These data have been extracted from published and draft EPA reports on these performance tests (7-10).

These test results are significant in that they reveal that well operated incinerators, industrial boilers, and process kilns are capable of achieving a 99.99 percent DRE. All of the incinerators tested achieved this level of performance for candidate POHC compounds in concentrations greater than 1000 parts per million (ppm) in the waste feed. Candidate POHC compounds below 500 ppm frequently were not destroyed to 99.99 percent.

This phenomenon, which was also observed in tests of other thermal destruction devices, was unexpected. A number of possible explanations have been advanced. At the very low stack emission concentrations necessary to demonstrate 99.99 percent DRE for sub-500 ppm POHCs, sampling and analysis techniques may be limiting. Also at these low emission levels, a sufficient amount of POHC may actually be formed as an incomplete combustion or recombination by-product from other materials in the wastes (or fossil fuels in the case of industrial processes) to produce sub-99.99 percent DRE.

EPA is conducting research to assess this concentration phenomenon. From a regulatory standpoint, however, this is not currently perceived as a problem

TABLE 5--INCINERATOR PERFORMANCE AND STACK EMISSIONS DATA
(Reported As Averages For Each Site)

FACILITY TYPE	O_2 (%)	CO (ppm)	THC (ppm)	DRE[a] (NUMBER OF NINES)	PARTICULATE (mg/m^3)	HCl CONTROL
(1) Commercial Rotary Kiln/ Liquid Incinerator	10.5	7.9	<1.0	99.9993%	1508	99.4%
(2) Commercial Fixed Hearth, Two Stage Incinerator	11.4	6.9	1.0	99.994%	400	98.3%
(3) On-site Two-Stage Liquid Incinerator	8.3	10.5	6.4	99.994%	61	99.7%
(4) Commercial Fixed Hearth, Two-Stage Incinerator	11	14.8	1.4	99.997%	200	(b)
(5) On-Site Liquid Injection	12.1	13.0	<1.0	99.99997%	207	(b)
(6) Commercial Two-Stage	9.9	1.4	<1.0	99.998%	900	(b)
(7) On-Site Rotary Kiln	9.7	544	61.7	99.9993%	23	99.9%
(8) Commercial Two-Stage Fixed Hearth Incinerator	13.6	2.6	1.6	99.996%	169	98.3%

(a) Mass weighted overage for all POHCs >100 ppm in waste.

(b) This facility did not employ a control device for HCl. However, HCl emissions were less than the 1.8 kg/hr emission standard due to low chlorine content in the waste feed stream.

TABLE 6--SUMMARY OF BOILER PERFORMANCE

Facility Type	Load (%)	O_2(%)	Residence Time (sec)	Average Volumetric Heat Release Rate KW//m^3	DRE[d]	W/F[a] (%)	NO_x[b] (ppm)	CO[b] (ppm)
(1) Watertube Stoker	100	6-16	1.2	509	99.98	40	163-210	900-1200
(2) Packaged Firetube	25	4-6	0.8	739	99.991	0.1-05	40-65	47-88
(3) Field Erected Watertube	26	10	2	78	99.9996	37	61-96	18-21
(4) Converted Stoker	78	4-6	1.1	339	99.998	18-48	193-250	75-127
(5) Packaged Watertube	36-73	6-7	1.1-0.5	960	99.995	19-56	164-492	83-138
(6) Converted Watertube	53	7-11	2	107	99.98	8.7-10.1	243-328	109-139
(7) Modified Firetube	44	8	0.4	807	99.998	100	67-74	146-170
(8) Tangentially Fired Watertube	100	6	2	180	99.991	2.4-4.3	393-466	142-201
(9) Packaged Watertube	65	2	1.8	343	99.998	8.2	64-78 410-1125[c]	46-750
(10) Packaged Firetube	50-100	3-8	0.7-0.3	1240	99.999	100	85-203	20-135
(11) Packaged Watertube	82	4	1.8	269	99.9997	49	154-278	102-119

(a) W/F = waste heat input as a % of total heat input
(b) range of average values across individual sites and runs including baseline
(c) higher values are for high nitrogen waste firing
(d) mass weighted average for all POHCs in the waste >100 ppm

TABLE 7--SUMMARY OF INDUSTRIAL KILN PERFORMANCE

FACILITY TYPE	TEST[a]	DRE[b] (NO. NINES)	PARTICULATES (kg/MG)	HCl_1 (kg/hr)	NO_x (ppm)	SO_2 (ppm)	W/F(%)(c)
(1) Wet Process Cement Kiln (Non-atomized Waste)	W	2.2	.27	.36	68	450	25
	B	-	.26	.09	136	279	-
(2) Wet Process Cement Kiln (Atomized Waste)	W	4.6	.27	2.1	478	265	15
	B	-	.26	.6	371	636	-
(3) Dry Process Cement Kiln (Non-atomized Waste)	W	4.8	-	11.5	814	19	45
	B	-	-	1.3	620	7	-
(4) Dry Process Cement Kiln (Atomized Waste)	W	4.2	-	.47	486	27	15
	B	-	-	.25	680	27	-
(5) Lime Kiln (Atomized Waste)	W	4.7	.11	.20	446	596	30
	B	-	.10	.09	386	553	-
(6) Shale Aggregate Kiln (Atomized Waste)	W	>4.0	.33	2.1	-	-	100
(7) Clay Aggregate Kiln (Atomized Waste)	W	4.8	0.58	0.023	162	1130	59
(8) Clay Products Kiln (Atomized Waste)	W	>4.0	.002	0.84	-	-	100

(a) W = waste testing, B = baseline (no waste firing)

(b) DRE = destruction and removal efficiency (e.g., 4.5 nines = 99.995%)

(c) % of total heat input provided by waste fuel

since few if any of the low concentration compounds in the wastes identified in the EPA test program would have actually been selected as POHCs in trial burns, if existing EPA guidance on POHC selection were employed.

Industrial boilers, particularly the larger water tube units, are acceptable devices for waste destruction. Cement kilns, lime kilns, and light weight aggregate kilns with adequate combustion control and waste atomization all met or exceeded the 99.99 percent DRE. It is also important to note that in all cases the destruction and removal efficiencies observed were due to destruction rather than removal or capture of hazardous organics. Ash, scrubber water, and air pollution control device residues were typically below detection limits for POHCs and organics in general.

All incinerators and industrial process kilns tested met or approached the RCRA HCl removal standard. Industrial boilers typically have no existing controls for HCl, but none exceeded the 4 lb/hr emission standard since wastes with low net chlorine content were employed.

Compliance with the particulate standard of 180 mg/Nm 3 was not achieved at half of the incinerators tested. Particulate control devices were operated at five of the eight facilities, and two of these five failed to achieve the standard. Two of the three facilities without control devices also failed the particulate standard. Data from this study suggest that any facility firing wastes with ash content greater than 0.5 percent will need a particulate control device to meet the standard.

No significant changes in particulate emissions were observed for industrial boilers and certain of the industrial process kilns when they fired waste fuels.

Some increased emissions have been observed in kilns employing electrostatic precipitators (ESP) for particulate control. These increases were attributed to changes in the electrical resistivity of the particles due to the presence of increased chloride levels. Adjustments in ESP operation or controlling chlorine input could correct this in most cases.

Analysis of the data from the incinerator test program revealed that there was no absolute level of mean combustion temperature, mean gas phase residence time, or carbon monoxide emission concentration which correlated with achieving 99.99 percent DRE. It appears at this time that any parametric relationships between DRE and these parameters are in all likelihood facility specific and that waste characteristics, waste atomization, and combustion chamber mixing likely play an equally important role in achieving high DRE. Analysis did reveal, however, that CO and total hydrocarbon (THC) emissions may provide indication of changes in incinerator performance and gross malfunctions in the combustion process. Similar observations of this were apparent in the boiler emission test results.

Data from the industrial boiler testing indicated that a relationship existed between NO_x formation (through thermal NO), furnace volumetric heat release rates and DRE. Higher NO_x emissions and higher volumetric heat release rates generally corresponded with higher measured DREs. DREs less than 99.99 percent were found to generally correspond to NO_x gas concentrations of less than 250 ppm and volumetric heat release rates less than 500 kW/M^3. The higher the NO_x and volumetric heat release rates, the higher the range in measured POHC DRE. These trends are felt to indicate that lower boiler loads may be more likely to result in lower DREs and that the temperature dependence of POHC destruction is more significant than furnace residence time. This conclusion

is not meant to indicate a definite relationship but rather a potential trend that warrants further investigation.

In the case of industrial kilns, NO_x emissions were not significantly affected by waste combustion. NO_x concentrations vary over time at the same kiln and are affected by oxygen input, primary to secondary air ratio, and temperatures. SO_2 emissions, however, generally decreased when waste fuel was used to replace a sulfur-containing fossil fuel, SO_2 emissions were found to be a function of several variables, such as sulfur loading, oxygen input, and temperatures. Cement kilns can be operated to obtain low SO_2 concentrations. Lime kilns are operated at higher SO_2 levels deliberately to avoid sulfur in the lime product.

The current RCRA standards regulate destruction and removal only for the major hazardous compounds in the waste. Under poor combustion conditions, many compounds may only partially decompose and form products of incomplete combustion (PICs) which are also hazardous compounds of concern if emitted. For the purpose of the EPA test program, compounds were considered to be PICs if they were regulated organic compounds (i.e., listed in Appendix VIII of CFR 40 Part 261) which were detected in stack emissions, but not present in the waste feed at concentrations greater than 100 ppm. Table 8 summarizes the PICs most frequently identified in the EPA testing of incinerators and industrial boilers. At this writing, detailed PIC analyses have been completed for only three cement kiln tests. The most common PICs identified during these tests were benzene, benzaldehyde, toluene, and various naphthalenes.

For incinerators the total mass emission of PIC compounds was typically equal to or less than the emissions of POHC. Data from the tests suggest that benzene, toluene, chloroform, tetrachloroethylene, and naphthalene have a high potential for appearing as by-products of the combustion of organic wastes.

TABLE 8--PICs MOST FREQUENTLY DETECTED IN STACK EMISSIONS

PIC	NUMBER OF FACILITIES	CONCENTRATION (ng/l)
Incinerators		
Benzene	6	12-670
Chloroform	5	1-1,330
Bromodichloromethane	4	3-32
Dibromochloromethane	4	1-12
Naphthalene	3	5-100
Bromoform	3	0.2-24
Chlorobenzene	3	1-10
Tetrachloroethylene	3	0.1-2.5
1,1,1-Trichloroethane	3	0.1-1.5
Toluene	2	2-75
o-Nitrophenol	2	25-50
Methylene chloride	2	2-27
Phenol	2	4-22
Boilers		
Chloroform	5	4.2-1900
Tetrachloroethylene	5	0.3-760
Chloromethane	4	4.6-410
Methylene chloride	4	83-2000
Benzene	3	9.4-270
1,1,1-Trichloroethane	3	5.9-270
1,2-Dichloroethane	3	1.3-1200
1,1-Dichloroethylene	2	0.21-38
1,1,2,2-Tetrachloroethane	2	4.6-16
Toluene	2	46-960

For industrial boilers total PIC mass emissions were about one order of magnitude or greater than mass emissions of POHC. Chloromethane, methylene chloride, and chloroform accounted for more than 75 percent of the total chlorinated PICs. Toluene contributed the bulk of total nonchlorianted PICs.

EPA is conducting continuing research to assess the nature and magnitude of PIC emissions from hazardous waste thermal destruction. Current data suggest that for thermal destruction facilities which are achieving good POHC DRE, PIC emissions are not of environmental concern. Consequently, the EPA does not currently have plans to regulate PICs under RCRA. EPA's research program is striving to assure that potential PIC problems do not exist for wastes not yet tested or for marginal thermal destruction conditions (e.g., DRE failure conditions). Understanding the mechanisms for PIC formation and for PIC control through optimization of combustion conditions is therefore quite important.

CONCLUSION

Thermal destruction is an effective and broadly applicable technique for destruction of organic hazardous waste. Performance tests conducted by EPA have indicated that incinerators and many high temperature industrial processes are capable of achieving existing performance and emissions standards.

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